CO-CHANNEL WIRELESS COMMUNICATION METHODS AND SYSTEMS USING NONSYMMETRICAL ALPHABETS

Cross-Reference to Provisional Applications

This application claims the benefit of Provisional Application Serial No. 60/457,043, entitled *Satellite Assisted Push-To-Send Radiotelephone Systems and Methods*, filed March 24, 2003; Provisional Application Serial No. 60/457,118, entitled *Radio Frequency Communication Systems and Methods That Use Polarization Orthogonality to Double Channel Capacity*, filed March 24, 2003; Provisional Application Serial No. 60/473,959, entitled *Systems and Methods That Enable Co-Channel Communications With a Base Station of a Plurality of Radioterminals*, filed May 28, 2003; and Provisional Application Serial No. 60/477,522, entitled *Satellite Assisted Push-To-Send Radioterminal Systems, Methods and Protocols*, filed June 11, 2003, all of which are assigned to the assignee of the present invention, the disclosures of all of which are hereby incorporated herein by reference in their entirety as if set forth fully herein.

Field of the Invention

This invention relates to wireless communications methods and systems, and more particularly to wireless communication systems and methods that can communicate co-channel.

Background of the Invention

Polarization diversity receiving systems and methods are well known in wireless communications. For example, a wireless terminal may transmit a linearly-polarized signal that may be received by orthogonally polarized antennas (e.g., horizontal and vertical polarization) at a base station (terrestrial or space-based) to thereby separately receive orthogonally polarized portions of the transmitted signal. The orthogonally polarized portions may be combined to effectively increase link robustness, since many channel degradations such as fading, are largely uncorrelated when comparing antennas of orthogonal polarizations. See for example, U.S. Patent

6,526,278 to Hanson et al. entitled *Mobile Satellite Communication System Utilizing Polarization Diversity Combining*; U.S. Patent 5,724,666 to Dent entitled *Polarization Diversity Phased Array Cellular Base Station and Associated Methods*; U.S. Patent 6,418,316 to Hildebrand et al. entitled *Increasing Channel Capacity of Wireless Local Loop via Polarization Diversity Antenna Distribution Scheme*; and U.S. Patent 6,445,926 to Boch et al. entitled *Use of Sectorized Polarization Diversity as a Means of Increasing Capacity in Cellular Wireless Systems.*

Other systems and methods that use polarization effects in wireless communications are described in the following publications: Andrews et al., *Tripling the Capacity of Wireless Communications Using Electromagnetic Polarization*, Nature, Vol. 409, January 18, 2001, pp. 316-318; Wolniansky et al., *V-BLAST: An Architecture for Realizing Very High Data Rates Over the Rich-Scattering Wireless Channel*, Invited paper, Proc. ISSSE-98, Pisa, Italy, Sept. 29, 1998, pp. 295-300; and Cusani et al., *A Simple Polarization-Recovery Algorithm for Dual-Polarized Cellular Mobile-Radio Systems in Time-Variant Faded Environments*, IEEE Transactions in Vehicular Technology, Vol. 49, No. 1, January 2000, pp. 220-228.

It is also known to use diversity concepts to increase the capacity of wireless communications. See, for example, the following publications: Miller et al., *Estimation of Co-Channel Signals With Linear Complexity*, IEEE Transactions on Communications, Vol. 49, No. 11, November 2001, pp. 1997-2005; and Wong et al., *Performance Enhancement of Multiuser MIMO Wireless Communications Systems*, IEEE Transactions on Communications, Vol. 50, No. 12, December 2002, pp. 1960-1970.

Summary of the Invention

Some embodiments of the present invention transmit wireless communications from at least two radioterminals to a base station co-channel over a return link using a return link alphabet, and transmit wireless communications from the base station to the at least two radioterminals over a forward link using a forward link alphabet that has more symbols than the return link alphabet. As used herein, the term "co-channel" indicates signals that overlap in time and space, and that use the same carrier frequency, the same time slot if the signals are Time Division Multiple Access (TDMA) signals, and the same spreading code if the signals are Code Division Multiple Access (CDMA) signals, such that the two signals collide at a receiver.

Embodiments of the present invention can allow the co-channel signals to be decoded or deciphered at the receiver, and can allow the radioterminals to use a smaller return link alphabet which can reduce the power dissipation at the radioterminals.

In some embodiments of the present invention, the wireless communications are transmitted from the base station to the radioterminals non-co-channel over the forward link using the forward link alphabet that has more symbols than the return link alphabet. In yet other embodiments, co-channel transmissions may be used. In some embodiments, wireless communications are transmitted from the at least two radioterminals to at least one antenna at the base station co-channel over a return link using a return link alphabet. In other embodiments, these transmissions are made to at least one multiple-polarized antenna at the base station. In yet other embodiments, these transmissions are made to a plurality of multiple-polarized antennas at the base station. In still other embodiments, these transmissions are made to a plurality of multiple-polarized antennas in a single sector of the base station. In some embodiments, the wireless communications are transmitted to the plurality of multiple-polarized antennas in a sector if the at least two radioterminals are separated by more than a predetermined distance. In other embodiments, these transmissions are made to at least one multiple-polarized antenna in at least two sectors of the base station. In yet other embodiments, these transmissions are made to at least one multiple-polarized antenna at a first base station and at least one multiple-polarized antenna at a second base station. In still other embodiments, these transmissions are made from a single linearly-polarized antenna at each of the at least two radioterminals.

Other embodiments of the present invention transmit wireless communications from at least two radioterminals to a base station over a return link using a return alphabet and transmit wireless communications from the base station to the at least two radioterminals co-channel over a forward link using a forward link alphabet that has more symbols than the return link alphabet. In other embodiments, as was described above, the transmission from the radioterminals to the base station may be non-co-channel or co-channel. Moreover, the wireless communications may be transmitted from the base station to at least one antenna at each of the at least two radioterminals, to at least one multiple-polarized antenna at each of the at least two radioterminals and/or to a plurality of multiple-polarized antennas at each of the at least two radioterminals, co-channel over a forward link using a forward link alphabet

that has more symbols than the return link alphabet, as was described above. Transmission from the base station may use at least one antenna, at least one linearly-polarized antenna, at least two linearly-polarized antennas, at least two linearly-polarized antennas in a sector, at least one linearly-polarized antenna in at least two sectors and/or at least one linearly-polarized antenna at two or more base stations, as was described above.

In other embodiments of the present invention, wireless communications are received from a base station at a first radioterminal and at least one second radioterminal that is proximate the first radioterminal over a forward link, co-channel. The wireless communications are relayed from the at least one second radioterminal to the first radioterminal over a short-range wireless link. The wireless communications that are relayed to the first radioterminal from the at least one second radioterminal over the short-range wireless link are used to process the wireless communications that are received from the base station at the first radioterminal. Moreover, these embodiments may be combined with any of the embodiments that were described above.

Still other embodiments of the present invention bidirectionally transmit wireless communications co-channel in time division duplex from at least two radioterminals to a base station over a return link using a return link alphabet, and from the base station to the at least two radioterminals over a forward link using a forward link alphabet that has more symbols than the return link alphabet. These embodiments also may be combined with any of the embodiments that were described above.

It will be understood by those having skill in the art that embodiments of the present invention were described above primarily with respect to method aspects. However, other embodiments of the present invention provide systems, base stations and radioterminals according to any of the embodiments that were described above.

Brief Description of the Drawings

Figures 1-3 and 4A-4B are diagrams of co-channel wireless communications according to various embodiments of the present invention.

Figure 5A is a diagram of radioterminal to base station communications according to embodiments of the present invention.

Figure 5B is a diagram of base station to radioterminal communications according to embodiments of the present invention.

Figure 5C is a diagram of base station to radioterminal communications according to other embodiments of the present invention.

Figures 6A-6B are block diagrams of receivers that may be used in Figures 5A-5C according to embodiments of the present invention.

Figure 7 graphically illustrates simulated receiver performance for signals in Rayleigh fading channels according to some embodiments of the present invention.

Figure 8 is a diagram of base station to radioterminal bidirectional communications according to embodiments of the present invention.

Figure 9 is a block diagram of a receiver and transmitter that may be used in embodiments of Figure 8.

Figure 10 is a block diagram of a receiver that may be used in Figure 9 according to embodiments of the present invention.

Figure 11 is a block diagram of a transmitter that may be used in Figure 9 according to embodiments of the present invention.

Figures 12 and 13 are diagrams of radioterminals and base stations, respectively, according to embodiments of the present invention.

Detailed Description

The present invention now will be described more fully hereinafter with reference to the accompanying drawings, in which embodiments of the invention are shown. This invention may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. Like numbers refer to like elements throughout.

Some embodiments of the present invention may arise from a recognition that it is possible to configure two physically distinct radioterminals to transmit to a base station, also referred to as a base transceiver station (BTS), co-channel, using the same return-link radio-channel resource(s) while still being able, at the BTS, to reliably demodulate and reconstruct (i.e., decode) the two data streams of the two physically distinct radioterminals. It is also possible to configure a BTS to transmit to two physically distinct radioterminals co-channel, over the same forward-link radio-

channel resource(s), while each of the two distinct radioterminals is able to reliably demodulate and reconstruct the information intended for it. The two physically distinct radioterminals may thus communicate bi-directionally with a BTS, co-channel, in some embodiments, using no more channel resource(s) than a single radioterminal would use. The signal processing techniques that make this possible, according to some embodiments of the invention, can exploit the multipath scattering nature of the radiochannel and/or the multi-dimensional nature of space and its relationship to electro-magnetic wave propagation. Moreover, embodiments of the invention can be extended to allow three or more physically distinct radioterminals to communicate co-channel with a BTS without using any more radiochannel resource(s) than a single radioterminal would.

Some embodiments of the present invention may also arise from a recognition that co-channel communications may be more beneficial for an infrastructure (base station) receiver than for a radioterminal receiver, because an infrastructure transmitter may not be power limited and may thus resort to a higher-alphabet modulation format (i.e. 8-PSK, 16-QAM, 64-QAM, etc.) to increase channel capacity on a forward link. In contrast, a radioterminal's transmitter may be power limited and may thus be constrained to lower-alphabet modulation formats (i.e. QPSK, GMSK, etc.). Thus, the ability of two or more radioterminals to send information to an infrastructure element (base station) co-channel may be used advantageously to increase channel capacity on the return link(s). According to some embodiments, therefore, base stations and radioterminals may be configured to utilize different modulation alphabets on forward and return links with a return link alphabet having a smaller number of distinct states (symbols) than a forward link alphabet, and with at least some infrastructure (base station) receivers of the system configured for co-channel communications, as will be described in further detail below.

Figure 1 is a diagram of co-channel wireless communications using nonsymmetrical alphabets according to some embodiments of the present invention. As shown in Figure 1, wireless communications are transmitted from at least two radioterminals **110a** and **110b** to a base station (BTS) **120** co-channel over a return link **130** using a return link alphabet having return link symbols S_R. As also shown in Figure 1, wireless communications are transmitted from the base station **120** to the at least two radioterminals **110a** and **110b** over a forward link **140** using a forward link alphabet having forward link symbols S_F, wherein the forward link alphabet has more

symbols than the return link alphabet. In other words, $S_F > S_R$. In some embodiments, the wireless communications are transmitted from the base station **120** to the at least two radioterminals **110a** and **110b** non-co-channel over the forward link **140** using the forward link alphabet that has more symbols S_F than the return link alphabet S_R.

Still referring to Figure 1, the wireless communications are transmitted from the at least two radioterminals **110a** and **110b** to at least one antenna **122** at the base station **120** co-channel over the return link **130** using the return link alphabet. In some embodiments, the at least one antenna **122** is at least one multiple-polarized antenna. In other embodiments, the at least one antenna **122** is a plurality of multiple-polarized antennas.

In still other embodiments, the base station **120** includes a plurality of sectors using sectorization techniques that are well known to those having skill in the art. In some embodiments, the at least one antenna **122** comprises a plurality of multiple-polarized antennas in a single sector of the base station, such that wireless communications are transmitted from the at least two radioterminals **110a** and **110b** to the plurality of multiple-polarized antennas in the single sector of the base station **120** co-channel over the return link **130** using the return link alphabet. In other embodiments, the wireless communications from the at least two radioterminals **110a** and **110b** are transmitted to a plurality of multiple-polarized antennas **122** in the sector of the base station **120** co-channel over the return link **130** using the return link alphabet if the at least two radioterminals are separated by more than a predetermined distance **D**. In still other embodiments, the wireless communications are transmitted from the at least two radioterminals **110a** and **110b** to at least one multiple-polarized antenna **122** in at least two sectors of the base station **120** co-channel over a return link using the return link alphabet.

Figure 2 is a diagram of co-channel wireless communications using nonsymmetrical alphabets according to other embodiments of the present invention. As shown in Figure 2, the base station **120** is a first base station. Wireless communications are transmitted from at least two radioterminals **110a** and **110b** to at least one multiple-polarized antenna **122** at the first base station and at least one multiple-polarized antenna **222** at a second base station **220** co-channel over a return link **130** using a return link alphabet. In any of the embodiments of Figures 1 and/or 2, wireless communications may be transmitted from a single linearly-polarized

antenna **112a, 112b** at each of the at least two radioterminals **110a, 110b** to the base station **120, 220** co-channel over the return link **130** using the return link alphabet.

Accordingly, some embodiments of Figures 1 and 2 allow co-channel transmissions from radioterminals to a base station using a small element alphabet in conjunction with non-co-channel transmissions from the base station to the radioterminals using a larger element alphabet. The number of antenna elements at the base station may be operative within a given sector of a base station, distributed over more than one sector of a base station and/or distributed over a plurality of base stations. As such, intra-sector co-channel return link communications may be provided, as well as inter-sector and inter-base station return link co-channel communications, to provide potentially improved capacity characteristics. Moreover, in some embodiments, intra-sector co-channel communications between two or more radioterminals and a base station may only be allowed in response to a distance **D** between the radioterminals. Since the system can know the position of the radioterminals, based on, for example, GPS or other techniques, radioterminals that are, for example, **D** meters or more apart may be allocated co-channel resources. Otherwise, non-co-channel resources may be allocated. The distance **D** may be selected so as to provide sufficient multipath differentiation from the signals that originate from the two radioterminals that are transmitting co-channel.

Figure 3 is a diagram of co-channel wireless communications using nonsymmetrical alphabets according to still other embodiments of the present invention. As shown in Figure 3, wireless communications are transmitted from at least two radioterminals **310a, 310b** to a base station **320** over a return link **330** using a return link alphabet having return link symbols $\mathbf{S_R}$. Wireless communications are also transmitted from the base station **320** to the at least two radioterminals **310a, 310b** co-channel over a forward link **340** using a forward link alphabet having forward link symbols $\mathbf{S_F}$, wherein the forward link alphabet has more symbols than the return link alphabet. In other words, $\mathbf{S_F} > \mathbf{S_R}$.

Embodiments of Figure 3 may be employed where it is desirable to relay much more data to the radioterminals **310a, 310b** from the base station **320** than to the base station **320** from the radioterminals **310a, 310b**. This may be the case when the radioterminals may be receiving large files from the base station, whereas the radioterminals are only sending back mouse clicks and/or other small amounts of data. Embodiments of Figure 3 use a larger element alphabet in conjunction with co-

channel communications to serve two or more terminals, while the radioterminals use a smaller element alphabet and may communicate non-co-channel with the system. In other embodiments, wireless communications are transmitted from the at least two radioterminals **310a**, **310b** to the base station **320** co-channel over the return link **330** using the return link alphabet.

Still referring to Figure 3, in some embodiments, the wireless communications are transmitted from the base station **320** to at least one antenna **312a**, **312b** at each of the at least two radioterminals co-channel over the forward link using the forward link alphabet that has more symbols than the return link alphabet. In some embodiments, the at least one antenna **312a**, **312b** comprises at least one multiple-polarized antenna. In other embodiments, the at least one antenna **312a**, **312b** comprises a plurality of multiple-polarized antennas. In other embodiments, the at least one antenna **322** at the base station **320** comprises at least one linearly-polarized antenna, at least two linearly-polarized antennas, at least two linearly-polarized antennas in a single sector and/or a linearly-polarized antenna in at least two sectors, as was described above in connection with the antennas **122** of Figure 1. In still other embodiments, transmissions may occur to at least one linearly-polarized antenna at a first base station and at a second base station, as was described above in connection with Figure 2.

Figure 4A is a diagram of co-channel wireless communications according to yet other embodiments of the present invention. As shown in Figure 4A, wireless communications are received from a base station **420** at a first radioterminal **410a** and at at least one second radioterminal **410b** that is proximate the first radioterminal **410a**, over a forward link **440**, co-channel. The wireless communications from the at least one second radioterminal **410b** are relayed to the first radioterminal **410a** over a short-range wireless link **450**. The short-range wireless link may be based on Bluetooth and/or other technologies such as 802.11, UWB, etc. The first radioterminal **410a** uses the wireless communications that are relayed to the first radioterminal **410a** from the at least one second radioterminal **410b** over the short-range wireless link **450**, to process the wireless communications that are received from a base station **420** at the first radioterminal **410a** over the forward link **440**.

Accordingly, in embodiments of Figure 4A, the signals from one or more proximate radioterminals may be used to improve a quality measure such as a bit error rate, of the information that is being received from the base station **420**. It will also

be understood by those having skill in the art that embodiments of Figure 4 need not use a forward link alphabet that has more symbols than a return link alphabet. However, in other embodiments of the invention, embodiments of Figure 4 may be used with any of the embodiments of Figures 1-3, including the use of a forward link alphabet that has more symbols than a return link alphabet, co-channel communications from the radioterminals **410a**, **410b** to the base station **420**, and antenna configurations for the base station **422** and for the radioterminal antennas **412a**, **412b** similar to those described in connection with Figures 1-3.

Figure 4B is a diagram of co-channel wireless communications using nonsymmetrical alphabets according to still other embodiments of the present invention. Referring to Figure 4B, wireless communications are bi-directionally transmitted co-channel in Time Division Duplex (TDD) **450**. Time division duplex transmission is well known to those having skill in the art, and need not be described further herein. As shown in Figure 4B, bidirectional transmission co-channel in time division duplex proceeds from at least two radioterminals **460a**, **460b** to a base station **470** over a return link using a return link alphabet, and from the base station **470** to the at least two radioterminals **460a**, **460b** over a forward link using a forward link alphabet that has more symbols than the return link alphabet. The antennas **462a**, **462b** of the first and second radioterminals **460a**, **460b** may be configured as was described in Figures 1-4A above. Moreover, the antenna or antennas **472** of the base station **470** may be embodied as was described above in any of Figures 1-4A.

Additional discussion of co-channel wireless communications according to various embodiments of the invention now will be provided. Specifically, in accordance with "non-Time Division Duplex" (non-TDD) embodiments, the receiver of a radioterminal and the receiver of a BTS may be configured to operate on a plurality of signals that may be acquired via a plurality of spatially-separated and/or co-located antennas. The transmitter of a radioterminal may use a single antenna. The BTS may transmit the information that is intended for a first radioterminal from a first antenna and the information that is intended for a second radioterminal from a second antenna that may be spatially-separated from the first. The two radioterminals may use the same return-link channel resource(s) to transmit information to the BTS. The BTS may use the same forward-link channel resource(s) to transmit information to the two radioterminals. Figures 5A and 5B illustrate antenna configurations of

non-TDD embodiments. It will also be understood that some embodiments of Figures 5A and 5B may be used in TDD mode as well.

Those skilled in the art will recognize that the M dual-polarized (or cross polarized) receiver antennas **512** of a radioterminal **510**, as illustrated in Figure 5B, may be replaced by M triple (x, y, z) -polarized, linearly-polarized, circularly-polarized and/or other type of receiver antennas. In some embodiments, only some of the M dual-polarized receiver antennas **512** of a radioterminal **510**, as illustrated in Figure 5B, may be replaced with triple-polarized, linearly-polarized, circularly-polarized, and/or other type of antennas, and that the value of M may be different for different radioterminals. In still other embodiments, only one receiver antenna that has been tapped at different points may be used on a radioterminal to provide a plurality of signal inputs to the radioterminal's receiver. It will also be understood by those of skill in the art that the N dual-polarized receiver antennas **540** of a BTS, as illustrated in Figure 5A, may be replaced in part or in entirety by triple (x, y, z) - polarized, linearly-polarized, circularly-polarized, and/or other type of receiver antennas. Finally, those having skill in the art will also recognize that one or both of the linearly-polarized transmitter antennas **520** of a BTS, as illustrated in Figure 5B, may be replaced by a dual- or multi-dimensionally-polarized, circularly-polarized and/or other type of transmitter antenna(s) and that the linearly-polarized transmitter antenna **532** of a radioterminal **530** may be replaced by a dual-polarized, multi-dimensionally-polarized, circularly-polarized and/or other type of transmitter antenna.

Those having skill in the art will also recognize that embodiments of Figures 5A and 5B may be extended to accommodate L co-channel radioterminals ($L > 2$) by having L transmitter antennas **520** on the BTS with the λ^{th} such antenna ($\lambda = 1, 2, \ldots, L$) transmitting information intended for a corresponding λ^{th} radioterminal.

Referring now to Figure 5C, in environments of dense radioterminal communications, such as in airports, convention centers, shopping malls, etc., one or more radioterminals **550b-550n** that is/are proximate to a first co-channel radioterminal **550a** may be configured to provide signals to the first receiving co-channel radioterminal **550a**. These signals may be relayed from the one or more proximate radioterminals **550b-550n** to the first receiving co-channel radioterminal **550a** via short-range wireless links **552**. The first receiving co-channel radioterminal **550a** may be configured to process the signals received from the one or more proximate radioterminals so as to improve a quality measure, such as the Bit Error

Rate (BER), of the information that is being received from the BTS. Still referring to Figure 5C, one or more radioterminals **550b'-550n'** that is/are proximate to a second co-channel radioterminal **550a'**, may be configured to provide signals to the second receiving co-channel radioterminal **550a'**. These signals may be relayed from the one or more proximate radioterminals **550b'-550n'** to the second receiving co-channel radioterminal **550a'** via short range wireless links **552**. The second receiving co-channel radioterminal **550a'** may be configured to process the signals received from the one or more proximate radioterminals, so as to improve a quality measure such as the BER of the information that is being received from the BTS. Accordingly, two or more radioterminals such as radioterminals **550a** and **550a'** may operate co-channel. It also will be understood that some embodiments of Figures 5C may be used in TDD mode as well.

A linear receiver processor, in accordance with the well-known Least Mean Squared Error (LMSE) criterion, is illustrated in Figure 6A for non-TDD embodiments. Those skilled in the art will recognize that other linear and/or non-linear receiver processors such as, for example, Kalman-based, least squares, recursive least squares, Zero Forcing (ZF) and/or Maximum Likelihood Sequence Estimation (MLSE) etc, may be used in lieu of and/or in combination with the receiver processor of Figure 6A. It also will be understood that Figure 6A illustrates a receiver for a BTS, but the principles and architecture may also be applied to a radioterminal.

In accordance with the illustrative BTS receiver antenna array **540** of Figure 5A, each antenna of the array **540** operates in two spatial dimensions and provides two signals to the receiver: one corresponding to the first spatial dimension "vertically-polarized" and the other corresponding to the second spatial dimension "horizontally-polarized." Thus, in accordance with the receiver antenna array that is illustrated in Figure 5A, the i^{th} antenna ($i = 1, 2, \ldots, N$) provides the receiver with the signal inputs V_i and H_i. As is illustrated in Figure 6A, each signal of the set $\{V_1, H_1, V_2, H_2, \ldots, V_N, H_N\}$ is operated on by two transversal filters **610a, 610b**; one for each co-channel source (radioterminal). The transversal filter outputs are summed at **620a, 620b**, to produce an output signal $S'j$ ($j = 1, 2$) based on which a decision is made at Blocks **630a, 630b** regarding the information symbol that has been transmitted by the j^{th} co-channel source. The transversal filters may be fractionally spaced, synchronously spaced, or single tap filters.

A computer simulation has been developed to assess the potential efficacy of the receiver of Figure 6A. Figure 7 graphically illustrates results of the computer simulation. The simulation modeled two co-channel radioterminals each transmitting independent data using Binary Phase Shift Keyed (BPSK) modulation with no Forward Error Correction (FEC) coding. The computer simulation modeled bursty transmission to emulate GSM. Within each burst of data, the channel was assumed static and an *a priori* known to the receiver training sequence (the burst mid-amble in GSM terminology) was used to estimate the transversal filter coefficients of the receiver. For each burst of data a new Rayleigh fading channel was picked pseudo-randomly. Flat Rayleigh-fading channels were assumed. Consequently, there was no Inter-Symbol Interference (ISI), only non-dispersive Co-channel Interference (CCI) due to the co-channel radioterminal. Thus, the receiver transversal filters reduced to single coefficient devices. The Bit Error Rate (BER) was evaluated for several receiver antenna configurations as described below.

As shown in Figure 7, for the case of four dual-polarized receiver antennas, the uncoded Rayleigh-faded channel BER for each co-channel radioterminal, at E_b/N_0 of 4 dB, is $\sim 10^{-3}$, whereas the BER of classical BPSK in Additive White Gaussian Noise (AWGN) with no fading, at the same E_b/N_0 of 4 dB is $\sim 10^{-2}$. Thus, the simulations appear to show that not only has the receiver of Figure 6A reduced the CCI, but significant diversity gain has also been attained.

To potentially improve further on the receiver performance of Figure 6A, a receiver architecture of Figure 6B may be used. The receiver of Figure 6B uses an estimate of the co-channel signal that has minimum noise and/or interference variance to cancel the CCI in the other co-channel signal, thus reducing or minimizing noise enhancement in the other co-channel signal, since a regenerated noise-free estimate of the CCI may now be used in the cancellation. Referring again to Figure 6A, the noise and/or interference variance of the two co-channel decision variables S'_1 and S'_2 may be estimated once per "data burst." The duration of the data burst may be chosen small relative to the rate-of-change of the channel state so as to validate a static (or quasi-static) channel assumption over a given data burst. The estimate of noise and/or interference variance of S'_j (j = 1, 2) may, for example, be based on the magnitude of a linear superposition of squared transversal filter weights, that may be involved in forming S'_j or may be based on processing of an *a priori* known to the receiver, training sequence. In the illustrative example of Figure 6B, the noise and/or

interference variance of S'_1 has been found to be smaller than the noise and/or interference variance of the second decision variable, S'_2. Thus, the decision that is made on S'_1, assumed correct, may be used to form an improved decision variable S''_2, based on which a decision or a series of decisions may be made regarding the data elements transmitted by the second co-channel radioterminal.

It will be understood by those of skill in the art that, in the illustrative receiver processing of Figure 6B, if the second decision variable was found to have lower noise and/or interference variance, a decision on that variable may have been made and that decision may have been used to form an improved first decision variable. It will also be understood by those skilled in the art that the principle and receiver architecture that is illustrated on Figure 6B, of first deciding on the least noise and/or interference variance variable and then using that decision to improve the noise and/or interference variance of the second decision variable, may be extended similarly to the general case where there are L co-channel radioterminals and, therefore, L decision variables at the receiver. In that case, the one (out of the L) decision variable with minimum noise and/or interference variance will be identified, a decision on it will be made, and that decision will be used to improve the noise and/or interference variance of the second least noise and/or interference variance variable. Then, a decision on the improved second least noise and/or interference variance variable will be made and now both decisions that have been made thus far can be used to improve the decision variable of the third least noise and/or interference variance variable, etc. Finally, it will be understood that even though the receiver principles and architectures of Figures 6A and 6B have been described using nomenclature associated with a BTS, the principles and receiver architectures of Figures 6A and 6B, and variations thereof, are also applicable to the radioterminal.

Figure 8 illustrates two radioterminals communicating co-channel bidirectionally with a BTS in a TDD mode according to other embodiments of the present invention. When the radioterminals **830** transmit information to the BTS antennas **840**, a BTS receiver of Figure 6A and/or 6B may be used to process the received waveforms, as was already described, and make decisions on the data that has been transmitted co-channel to the BTS antennas **840** by the radioterminals **830**. This function is illustrated by Block **910** of Figure 9. The BTS receiver of Figure 9 may also be configured to perform processing of the received waveforms in accordance with the well-known zero-forcing criterion thereby "forcing to zero", to

the extent that digital quantization effects and/or other implementation constraints may allow, the ISI and the CCI, at least over the span of the transversal filters used. This function is illustrated by Block **920** of Figure 9 and is further illustrated in greater detail in Figure 10.

Over the time interval of a TDD frame, the state of the channel may be assumed static or quasi-static provided that the TDD frame interval has been chosen sufficiently small. Thus, capitalizing on the reciprocity of the TDD channel over its static or quasi-static interval the transversal filter coefficients that have been derived by the BTS receiver to yield "zero" ISI and CCI at the BTS, may be used to process or pre-distort a BTS data vector **d** prior to transmitting it to the co-channel radioterminals. In TDD, the same BTS antenna array may be performing both receive and transmit functions. This function is illustrated by Block **930** of Figure 9 and is further illustrated in greater detail in Figure 11. It also will be understood that some embodiments of Figure 8 may be used in non-TDD mode, as well.

Given the above, the information that is transmitted by a BTS, co-channel, for a plurality of radioterminals, can arrive at the plurality of co-channel radioterminals free, or substantially free, of ISI and CCI. Thus, the receiver complexity of a radioterminal may be reduced and the radioterminal may only be equipped with a single linearly-polarized receiver antenna. Those skilled in the art will recognize that even in TDD mode the principles and receiver architectures that were described earlier for the non-TDD case can apply for both a BTS and a radioterminal. Also, those skilled in the art will recognize that the zero-forcing processing at a BTS receiver as illustrated in Figures 9 and 10 may be omitted and instead, the transversal filter coefficients derived from a LMSE processor (Block **910** of Figure 9) may be used for the transmitter processing (Block **930** of Figure 9) of a BTS. Accordingly, information that is received when wirelessly receiving at least two signals on the same carrier frequency, time interval, and/or code, from a corresponding at least two radioterminals, may be discriminated among the at least two signals.

Finally, it will be understood that, in all of the embodiments that have been described herein, a radioterminal may include a transceiver which itself includes a transmitter and a receiver, as illustrated in Figure 12, which perform the transmitting and receiving operations, respectively, that were described herein. The antenna of the radioterminal may be regarded as a component of the transceiver. Similarly, in all of the embodiments described herein, a base station may also include a transceiver

which itself includes a transmitter and a receiver, as illustrated in Figure 13, which perform the transmitting and receiving operations, respectively, that were described herein. The antenna of the base station may be regarded as a component of the transceiver.

In the drawings and specification, there have been disclosed embodiments of the invention and, although specific terms are employed, they are used in a generic and descriptive sense only and not for purposes of limitation, the scope of the invention being set forth in the following claims.